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A SOLID-STATE DOSIMETER BASED ON A NEW GLOW CURVE FOR BERYLLIA

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1. ABSTRACT

There is a need for a dosimeter which covers the dose range of Kilorads to Megarads, can be built by most laboratories and is easily operated. This paper describes such an equipment which has been designed using the thermoluminescent properties of beryllia. It is shown that some samples of beryllia have an orange glow curve at 280°C which is more intense than the blue emission at 180°C which is normally used. The intensity and spectral emission properties have been used to design a dosimeter based on a solid-state photodetection system. The system was designed primarily for dosimetry during terrestrial irradiation of electronic components and equipment intended for satellite applications. A number of other dosimetry applications with similar requirements could also benefit from this development.

2. INTRODUCTION

There is a growing demand for the use of complex semiconductor devices in systems which are exposed to ionizing radiation. This demand poses new problems in the area of satellite design where, due to weight restrictions, the simple expediency of shielding cannot always provide the solution. At present, components based on MOS technology (1) and microwave transistors (2) are known to be extremely radiation-sensitive and in practice these are tested on a routine basis. It is often necessary to irradiate complete equipment boxes in order to determine the effect of component sensitivity on system performance - especially in the case of microwave transistors where device/circuit interactions are more difficult to predict (3).

In the space radiation effects community, Van de Graaf machines (0,5 - 2 MeV electrons), gamma emitters (e.g. Co-60) and X-ray (bremsstrahlung) are commonly used for component and equipment level irradiations (4). Dosimetry techniques for these applications are limited if a reasonably wide range of cumulative doses is required. Ideally, for space simulation work, a dosimeter should cover the range of 1 Krad (Si) to 1 Mrad (Si) and be small enough to place inside equipment boxes to measure the radiation field which may be modified by the surrounding equipment structure. Dosimetry based on LiF thermoluminescent devices (TLD's) calibrated against ionisation chambers is the most commonly used technique for this type of work. LiF TLD's were developed primarily for personnel dosimetry where doses in the region of m rads (H_2O) to rads (H_2O) are encountered and relatively easily measured (5). There are several disadvantages associated with this technique which makes it difficult to use on a routine basis by operators outside the health physics field who have no specialized training in dosimetry. These disadvantages are :

(a) Need for specialized TLD "readers" comprising photomultiplier tubes and high voltage power supplies to "read" the glow curve (5);

(b) Need for complex post-reading annealing cycles (5) typically 1 hour heating to 400°C, cooling at a constant rate and 20 hour storage at 80°C;

(c) Above several hundred kilorads, LiF suffers radiation damage which reduces its sensitivity considerably in subsequent uses (5) typically by two thirds after 0.2 Mrad.

(d) Due to optical transparency and dose distribtion in the depth of the crystal, special correction factors are required to account for photons with energies less than 20 KeV (6).

(e) Reproducibility between crystals is such that individual serialisation and data logging is necessary if dose accuracies of better than ± 20% are required.

This paper describes a dosimeter which is based on the thermoluminescence of beryllia and eliminates most of the above disadvantages. Since the dosimeter is based on a new glow curve for beryllia, the latter will be described first before a detail description of the solid-state dosimeter itself is given.

3. BERYLLIA GLOW CURVES

Beryllia has been previously studied as a TLD material (7) because of its greater sensitivity to ionizing radiation and less complex annealing requirements compared with LiF (8). Past studies have not concentrated on the spectrum of the glow curve, but since the peak was reported (9) in the region of 350 nm, photomultiplier TLD "readers" similar to those developed for LiF have been used. The present authors have found that a number of beryllia samples exhibit a higher temperature peak which is more intense than the blue peak and, being orange, has the added advantage of being more easily detectable. Figure 1 shows glow curves for two beryllia samples which were irradiated with X-rays, one showing the "normal" blue peak, the other blue and orange peaks.

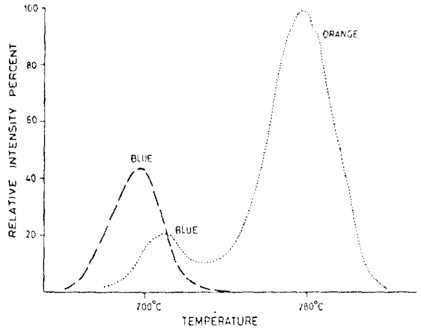

Fig 1. Relative intensities of glow peaks of beryllia discs after exposure to 50 Krad X-ray.

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Both samples were beryllia discs normally used as heat sinks on microwave power transistors and the glow curves were measured on the equipment described in Section 4. In a search for more orange samples, it was found that most showed at least one orange peak and one sample with two orange peaks was found. Of those with orange peaks only 5 out of 25 samples provided the intensity required for the simple read out system described. The heat sinks originated from microwave power transistors of European, U.S. and Japanese manufacture and there was no a priori method(color,structure,etc.)by which the glow curve could be determined.

In addition to evaluating beryllia recovered from microwave transistors, we purchased discs directly from two beryllia manufacturers, one batch from National Beryllia Corporation (U.S.) and two batches from Consolidated Beryllium (U.K.), all three batches gave blue emission.

Several beryllia samples having various emission characteristics from simple blue to blue with intense orange were spectrographically analysed to see if impurities might be the cause of the orange peak. Fig. 2 shows the results of the analysis together with the glow curve for each sample.

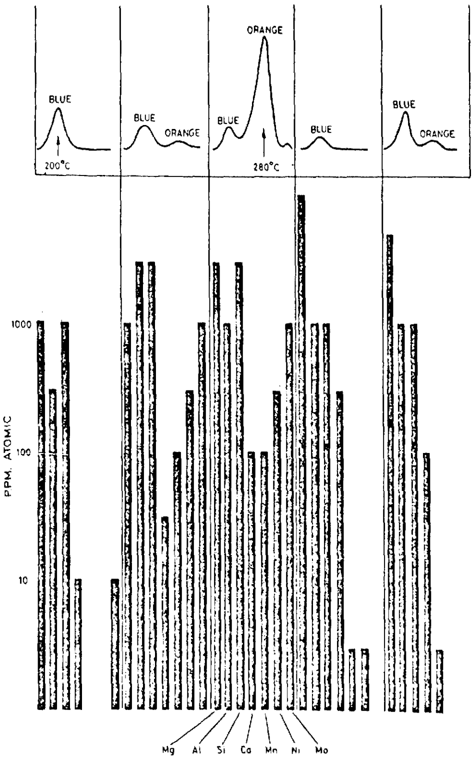

Fig 2. Glow curves and results of mass spectrographic analysis of various beryllia samples. Sequence of elements repeats for each column. Trace elements not shown.

It is apparent that no particular impurity or combination of impurities is responsible for the orange peak. Either it is due to a unique combination of some of the trace impurities or to trapping centers resulting from manufacturing methods which may give rise to different stresses in different samples. It has been suggested by previous authors that the blue peak which they studied may be due to an instrinsic defect in beryllia(9). It has been impossible to determine the basic cause of the orange glow curve, but, even with a limited supply of beryllia samples to draw from, a usable number of dosimeter discs were found. Selection of samples is a simple matter of irradiating a batch of beryllia discs to about 500 Krads and observing the glow curve in a semi-darkened room when they are placed on a hot plate at about 350°C.

It is possible that other workers may have used samples with orange peaks but since normal TLD readers do not allow visual access during read out, this peak could have been missed. In addition since beryllia is known to emit in the blue region of the spectrum, filters and photomultiplier tubes with S11 phosphor are used which would almost totally eliminate the orange peak. Figure 3 illustrates this point with a comparison of the relative responses of the S11 phosphor and the silicon photodetector used in the instrument described in the next Section.

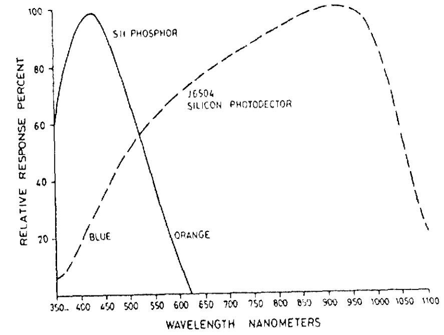

Fig 3. Comparative response of photomultiplier S11 phosphor and silicon photodetector.

4. DESCRIPTION OF READ-OUT EQUIPMENT

The read-out equipment has been designed to exploit the strong orange peak found in the flow curve of about 20% of the beryllia discs randomly sampled. One of the design aims of the equipment was to use, as far as possible, equipment normally available in an electronics laboratory.

The read-out equipment is shown schematically in Figure 4.

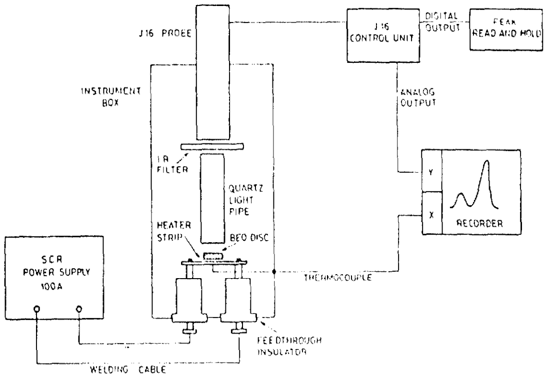

Fig 4. Schematic diagram of beryllia dosimeter read-out equipment.

The beryllia disc (5 mm diameter, 1.5 mm thick) is placed on the 0.5 mm thick steel heater strip through which is passed a current of 100 amps. from the SCR power supply. This current gives a heating rate of 10^{o}C sec^{-1} which has been found to be optimum for exciting an intense orange peak and allowing a read-out cycle time of about 1 minute. The light output from the surface of the opaque beryllia is guided up a quartz light pipe and through an infra-red filter to the photodetector. Silicon photodetector diodes with integrated operational amplifiers have been successfully used as a detection system but the present equipment uses a Tektronix J16 Solid State Photometer. Using an uncorrected probe type J6504 the J16 gives an analog output of 7 volts for the orange peak from a beryllia disc exposed to 5×10^{4} rads. The analog output of the J16 is fed to the Y axis of an X-Y recorder with the heater strip thermocouple driving the X axis to produce a glow curve. For routine dosimetry it is more convenient to take either the digital or analog output of the J16 and feed it to a peak detection and holding instrument. The heater, light pipe and photodetector assembly are mounted in a simple commercially available die-cast instrument box 15 x 10 x 5 cm. The front of the box is retained with spring latches which ensure adequate light tightness but allow easy access for placing beryllia discs on the heater strip.

5. CALIBRATION AND ACCURACY

The equipment described in the previous section has been calibrated using a 150 kV bremsstrahlung X-ray source (tungsten reflection target 0.09 mm Al. HVL). Figure 5 shows a typical calibration curve with the peak output from the detection system as a function of cumulative dose in rads (Si). The X-ray source had been previously calibrated using LiF TLD's to below their damage threshold dose to establish the dose rate at various working distances. Calibrations for both blue and orange glow curve are shown in Figure 5 and this demonstrates the difference in sensitivity for the two peaks.

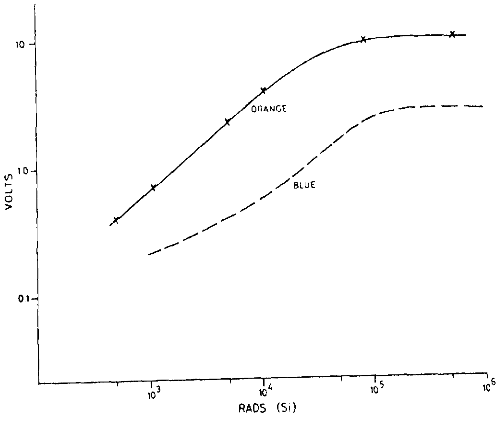

Fig 5. Calibration curves for blue and orange peaks for beryllia discs exhibiting both peaks.

These calibration curves were found to be reproducible and did not necessitate any more annealing than was provided by the 'read-out' cycle of heating to about 350^{o}C followed by a natural cool down to room temperature. Ten successive exposures of the same disc to the same nominal irradiation exposure gave a measured output within ± 2%, this being well within the reproducibility of the current-time product for the X-ray source. At least 3 of the 5 discs were found to lie on the same calibration curve within ± 5%, the other 2 were destructively analysed prior to establishment of the curve. The indications are that further discs presently being recovered from transistors will also follow the calibration curve. Exposure of two discs to Co-60 gamma radiation gave a measured output within 5% of each other and with 15% of the dose derived by calculation by knowing the source strength. No significant fading of response has been noted after several days exposure to a normal laboratory ambient, this is an advantageous feature of the orange peak which, lying at a high temperature, comes from a deep stable trap. Such a trap will also be free from spurious response such as triboluminiscence. An experiment was carried out using the beryllium window X-ray source and simultaneous exposure of beryllia discs and LiF TLD's covered by different thicknesses of aluminium to determine their energy dependence. Figure 6 shows that the relative response for beryllia closely follows that reported for an air ionisation chamber (10). The LiF response is also shown for comparison purposes, the shape of this curve is almost certainly due to the previously mentioned energy dependence of LiF at low photon energies (6). In fact the true shape of the LiF response curve below about 20 KeV is still very much under discussion (6).

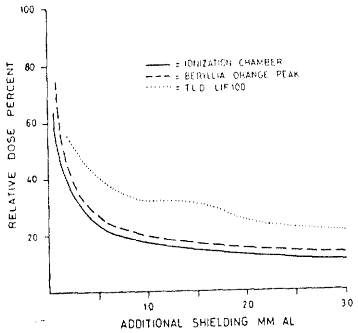

Fig 6. Relative response of ionization chamber, beryllia and LiF TLD100 for X-ray exposure with aluminium shields. Ionization chamber results from Ref 10.

6. CONCLUSIONS

It has been shown that many of the dosimetry problems associated with terrestrial irradiation experiments can be overcome by the use of a simple dosimeter with an easily realized solid state detection and read out system.

This is the first reported identification and exploitation of the high temperature orange peak in the beryllia glow curve. Using the orange peak for dosimetry allows the use of easily built read out equipment giving reproducible results over the range 1 Krad (Si) to 1 Mrad (Si) without the need for TLD annealing cycles and with no fading. There are good indications that the response is not very energy dependent between 10 KeV and 2 MeV and the system should lend itself to use in combination with space radiation experiments. There is presently great interest in the space radiation effects community regarding the calibration and usage of industrial X-ray inspection equipment as a source of ionising radiation (4). Such equipment lends itself well to this purpose but with its low effective energy requires small TLD's exhibiting less energy dependence than those currently available. The present beryllia dosimeter with its flatter energy response previously discussed should fill this need.

One major disadvantage of the present system at the moment is that the basic cause for the glow curve used is unknown. This situation is quite common in the development of any new TLD system (5) and should not deter potential users since our findings indicate that suitable material exists in sufficient quantity and can be easily selected. It is hoped that beryllia manufacturers may be in a better position to determine the basic reason from the effect and come forward with procedures to provide samples with consistent behavior.

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